

**THE PERFORMANCE EVALUATION OF DIFFERENT LOGICAL  
TOPOLOGIES AND THEIR RESPECTIVE PROTOCOLS FOR WIRELESS  
SENSOR NETWORKS**

**NAYEF ABDULWAHAB MOHAMMED ALDUAIS**

**A project thesis submitted in  
fulfillment of the requirement for the award of the  
Degree of Master of Electrical Engineering**



**FACULTY OF ELECTRICAL AND ELECTROINC ENGINEERING  
UNIVERSITI TUN HUSSEIN ONN MALAYSIA**

**JANUARY 2015**

## ABSTRACT

Wireless sensor networks (WSNs) are at present a standout amongst the most, guaranteeing areas in the field of information and communication technologies (ICT). This new technology has boundless potential for various applications in distinctive regions, including environmental research, medical application, military, transportation, stimulation, emergency administration, security, and smart spaces. However, several constraints of the sensor nodes are the principal obstacles in planning efficient protocols for WSNs. The major challenges of WSNs include energy dissipation; prolong the network lifetime and throughput. This thesis explores logical topologies in WSN. Logical topologies play the most significant role in the overall performance of the network, including its lifetime, routing efficiency, energy dissipation and overheads. A number of logical topologies have been proposed for WSNs including flat topology, cluster-distributed topology, cluster-centralized topology, and chain topology along with their corresponding routing protocols. In addition, the outcome of the study should definitely performed an important of those parameters of concerned. The simulation experiments are done by using NS-2.34 program for the logical topologies considered are cluster-distributed, chain-based, cluster-centralized and flat with the corresponding protocols of LEACH, PEGASIS, LEACH-C and MTE respectively, while MATLAB is used to plot the graphs. The performance metrics studied are the network lifetime, energy dissipation and aggregate data received at the base station. From the results it can be deduced, that the chain topology (PEGASIS) gives a better performance (network lifetime, energy dissipation and throughput at the base station) overall topologies (LEACH, LEACH-C and MTE).

## ABSTRAK

Rangkaian Sensor Tanpa Wayar (WSN) merupakan suatu sistem komunikasi yang sangat penting dalam bidang teknologi maklumat dan komunikasi (ICT). Teknologi yang baru ini mempunyai potensi yang sangat luas dalam berbagai aplikasi meliputi bidang yang khusus seperti penyelidikan alam sekitar, aplikasi pembuatan, ketenteraan, keselamatan dan ruang cerdas. Walaubagaimanapun, beberapa kekangan bagi nod sensor adalah penghalang utama, dalam merancang protokol yang efisien bagi WSN. Cabaran utama WSN termasuklah pelepasan tenaga, memanjangkan jangka hayat rangkaian dan truput. Tesis ini meneroka topologi logik dalam WSN. Topologi logik memainkan peranan yang penting dalam prestasi keseluruhan rangkaian termasuklah tempoh hayat, kecekapan penghalaan, pelepasan tenaga dan overhead. Beberapa topologi telah dicadangkan termasuklah topologi rata, topologi kluster teragih, topologi kluster pusat, dan topologi rantai. Ia juga mengambilkan protokol penghalaan masing-masing. Tambahan pula, hasil kajian ini akan memberikan impak yang baik kepada parameter berkenaan. Penyelakuan dilaksanakan menggunakan perisian NS-2.34 bagi topologi yang digunakan iaitu topologi rata, topologi kluster teragih, dan topologi kluster pusat. Protokol yang digunakan ialah LEACH, PEGASIS, LEACH-C dan MTE. Perisian MATLAB digunakan untuk melakarkan graf. Matrik prestasi yang dikaji ialah jangka hayat rangkaian, pelepasan tenaga dan data agregat yang diterima di stesen pangkalan. Daripada keputusan ini dirumuskan bahawa, topologi rantai (PEGASIS). Memberikan prestasi terbaik (jangka hayat, pelepasan tenaga dan truput stesen pangkalan) berbanding dengan topologi lain (LEACH, LEACH-C dan MTE).

## CONTENTS

<b>TITLE</b>	<b>i</b>
<b>DECLARATION</b>	<b>ii</b>
<b>DEDICATION</b>	<b>iii</b>
<b>ACKNOWLEDGEMENT</b>	<b>iv</b>
<b>ABSTRACT</b>	<b>v</b>
<b>ABSTRAK</b>	<b>vi</b>
<b>CONTENTS</b>	<b>vii</b>
<b>LIST OF TABLES</b>	<b>xi</b>
<b>LIST OF FIGURES</b>	<b>xii</b>
<b>LIST OF SYMBOLS AND ABBREVIATIONS</b>	<b>xiv</b>
<b>CHAPTER 1 INTRODUCTION</b>	<b>1</b>
1.1 Background of Project	1
1.1.1 Overview	1
1.1.2 Introduction of WSNs logical topologies	3
1.2 Problem statements	3
1.3 Project objectives	4
1.4 Scopes of Project	4
1.5 Thesis structure outline	5
<b>CHAPTER 2 LITERATURE REVIEW</b>	<b>6</b>
2.1 Wireless Sensor Networks	6
2.1.1 An Overview of WSNs	6
2.1.2 Characteristics of Sensor Nodes	7
2.1.3 Sensor node architecture	7
2.1.4 Types Of Sensor Networks	9
2.1.5 Wireless Sensor Network Applications	9
2.2 WSNs Challenges and Constraints	9
2.2.1 Limited energy	10
2.2.2 Low-quality communications	10

2.2.3	Resource-constrained computation.	10
2.2.4	Data processing	10
2.2.5	Scalability	11
2.2.6	Reliability	11
2.2.7	Responsiveness	12
2.2.8	Mobility	12
2.2.9	Power efficiency	12
2.2.10	Managing the design tradeoffs	12
2.3	Wireless Sensor Networks Logical Topologies	13
2.3.1	Flat Logical topology	13
2.3.2	Cluster Logical topology	14
2.3.2.1	Cluster types	15
2.3.3	Chain Logical topology	15
2.4	Protocols Of WSNs	16
2.4.1	Low-Energy Adaptive Clustering Hierarchy (LEACH) Protocol	16
2.4.1.1	Operation of LEACH	17
2.4.1.2	Cluster Head (CH) Selection	18
2.4.1.3	Cluster Formation Algorithm	19
2.4.1.4	Sensor Data Aggregation	20
2.4.2	Power-Efficient Gathering in Sensor Information Systems (PEGASIS) Protocol	23
2.4.2.1	Leader Selection	24
2.4.2.2	Data Transmission	25
2.4.3	LEACH-C Centralization Protocol	26
2.4.4	Minimum Transmission Energy (MTE ) Protocol	29
2.5	A Review of Evaluation Criteria	31
2.5.1	Evaluation measures related to energy usage	31
2.5.2	Evaluation measures related to the lifetime of the network	31
2.5.3	Evaluation measures related to scalability	32
2.5.4	Evaluation measures related to overhead and efficiency	33
2.6	Related work	33
2.7	Simulation Tools	35
2.7.1	NS-2 (simulator)	35
2.7.2	MATLAB	36

2.7.3	Plotting with MATLAB	36
<b>CHAPTER 3</b>	<b>METHODOLOGY</b>	<b>38</b>
3.1	Introduction	38
3.2	Project Flowchart	38
3.3	System Model and Assumptions	40
3.4	Wireless Sensor networks Logical Topologies with their corresponding routing protocols	41
3.4.1	Cluster-Distributed Topology based on LEACH Protocol	42
3.4.2	Chain Topology based on PEGASIS Protocol	42
3.4.3	Cluster- Centralization topology based on LEACH-	43
3.4.4	Flat topology based on MTE Protocol	43
3.5	Performance metrics	44
3.5.1	Evaluation measures related to Overall Energy consumption	44
3.5.2	Evaluation measures related to Network lifetime (Number of Surviving Nodes)	45
3.5.3	Evaluation measures related to Aggregate Data Received at BS	45
3.6	Simulation and Analysis Tools	45
3.6.1	Equipment's and Tools	46
3.6.2	Equipment's and Tools features	47
3.6.3	NS with MIT uAMPS extensions	47
<b>CHAPTER 4</b>	<b>SIMULATION AND ANALYSIS</b>	<b>48</b>
4.1	Performance studies on the impact of various parameters on the efficiency of the protocols in WSNs	48
4.1.1	Channel Propagation Model	49
4.1.2	Energy Model Used In the Simulations Experiments	52
4.1.3	Simulation parameters	53
4.1.4	Sensor field of size $M \times M$ meters	54
4.1.5	Effect of setting the initial energy value of the nodes	56
4.1.6	Effect of number of nodes variation an Energy; lifetime and throughout	57
4.1.7	Enhancement of LEACH protocol via selecting the optimum number of clusters	60
4.1.8	The effect of packet size variation	64
4.2	The efficiency of different logical topologies in WSNs	67

<b>CHAPTER 5</b>	<b>CONCLUSION AND FUTURE WORK</b>	<b>71</b>
5.1	Conclusions	71
5.2	Future works	72
	<b>REFERENCES</b>	<b>74</b>
	<b>APPENDICES</b>	<b>79</b>
	<b>VITA</b>	<b>88</b>



## LIST OF TABLES

Table 2.1	Comparison of routing protocols in WSN	27
Table 2.2	Comparison of LEACH and LEACH-C	28
Table 2.3	Advantages / Disadvantages for different topologies	29
Table 2.4	Summary of Related Works	34
Table 3.1	System model parameters	41
Table 3.2	WSNs Topologies with their corresponding routing protocols	42
Table 3.3	Equipment's and Tools features	47
Table 4.1	Simulation Model attributes and parameters value	53
Table 4.2	Max distance with area m x m	54
Table 4.3	Average of Energy consumption, No. alive nodes and throughput at the BS with variable number of nodes	58
Table 4.4	The optimum number of clusters with parameters of different values	61
Table 4.5	Compute Frame time with different packet sizes	65
Table 4.6	Simulation parameters values	68



## LIST OF FIGURES

Figure 2.1	The Wireless Sensor Network scenario	6
Figure 2.2	Architecture of a typical sensor node	7
Figure 2.3	Flat logical topology	14
Figure 2.4	Cluster Logical topology	14
Figure 2.5	Chain Logical topology	15
Figure 2.6	cluster head selection	17
Figure 2.7	Distributed cluster formation algorithm	20
Figure 2.8	Block diagram of the Beamforming algorithm	21
Figure 2.9	Example for PEGASIS Chain	24
Figure 2.10	Hierarchical PEGASIS protocol algorithm	25
Figure 2.11	Data Transmission	26
Figure 2.12	NS Directory structures	36
Figure 2.13	MATLAB 2-D plotting functions	37
Figure 3.1	Project Flowchart	39
Figure 3.2	A system model WSNs	41
Figure 3.3	Flowchart of the Performance metrics	44
Figure 3.4	Block diagram for equipment's and tools	46
Figure 4.1	Energy consumption Vs different frequencies	51
Figure 4.2	Network lifetime Vs different frequencies	51
Figure 4.3	Throughput at the BS Vs different frequencies	51
Figure 4.4	Radio model energy consumption	52
Figure 4.5	Average of Energy consumption, number alive nodes and amount data received at the BS with varied Simulation area size $m \times m$ (LEACH protocol)	55
Figure 4.6	Average of Energy consumption, number alive nodes and amount data received at the BS with varied Simulation area size $m \times m$ (LEACH, LEACH-C, and PEGASIS)	55

Figure 4.7	Average of No. rounds (Time) VS varied initial energy value. (LEACH)	56
Figure 4.8	Generator script code for node deployment randomly in the simulation area M x M meters	57
Figure 4.9	Percentage of Energy consumption and number alive nodes VS variable number nodes	59
Figure 4.10	Average of Energy consumption with variable number of nodes and number of clusters	62
Figure 4.11	Average number surviving nodes with variable number of nodes and number of clusters	63
Figure 4.12	Average throughput at the BS with variable number of nodes and number of clusters	63
Figure 4.13	Maximum TDMA frame time with variable packet size	65
Figure 4.14	Average Throughput at the BS with various packet sizes	66
Figure 4.15	Average total energy dissipation with variable data packet size	66
Figure 4.16	Figure shows the 100 sensor node random topology in an area of 200m x200m.	67
Figure 4.17	Energy Consumption VS Different Logical Topologies	68
Figure 4.18	No.Alive nodes VS Different Logical Topologies	69
Figure 4.19	Throughput at BS VS Different Logical Topologies	69
Figure 4.20	Average total energy dissipation, number of surviving node throughput at the base station for Different Logical Topologies. N_s 100, initial energy 3 joules	70

## LIST OF SYMBOLS AND ABBREVIATIONS

WSNs	-	Wireless sensor networks
BS	-	Base station
CH	-	Cluster head
LEACH	-	Low-Energy Adaptive Clustering Hierarchy
LEACH -C	-	Low-Energy Adaptive Clustering Hierarchy-Centralization
PEGASIS	-	Power-Efficient Gathering in Sensor Information Systems
MTE	-	Minimum-transmission-energy protocol
NS	-	Simulation Networks
ADC	-	Analogue to Digital Converter
OP	-	Operating System
PC	-	Personal Computer
MIT	-	Massachusetts Institute of Technology
uAMPS	-	Utah Associated Municipal Power Systems
$L$	-	A system loss factor not related to propagation
$h_r$	-	Height of the receiving antenna above ground
$h_t$	-	Height of the transmitting antenna above ground
$\lambda$	-	Wavelength of the carrier signal
$P_r(d)$		Receive power given a transmitter-receiver separation of $d$
$P_t$	-	Transmit power
$G_t$	-	Gain of the transmitting antenna
$G_r$	-	Gain of the receiving antenna
$d$	-	Distance between the transmitter and the receiver
$k$	-	Message data packet size
$E_{Tx}$	-	Energy model for the transmitter
$E_{Rx}$	-	Energy model of the receiver
$E_{\text{friss-amp}}$	-	Radio amplifier energy (Friss model)

$E_{\text{two-ray-amp}}$	-	Radio amplifier energy (two-ray ground attenuation model)
$E_{\text{elec}}$	-	Radio electronics energy
$X_{\text{max}}$	-	Maximum value of x in horizontal axis
$X_{\text{min}}$	-	Minimum value of x in horizontal axis
$Y_{\text{max}}$	-	Maximum value of y in vertical axis
$Y_{\text{min}}$	-	Minimum value of y in vertical axis
$E_{\text{CH}}$	-	Energy dissipated in the cluster-head node during a single frame
$C$	-	Optimum number of clusters
$N_s$	-	Number of nodes
$E_{\text{non-CH}}$	-	Energy dissipated in the non-cluster-head node during a frame
$M$	-	Area simulation m x m
$d_{\text{toBS}}$		Distance from the cluster-head to base station
$E_{\text{cluster}}$	-	Energy consumption in a cluster during the frame
$E_{\text{total}}$	-	Total energy for frame
$E_{\text{BF}}$	-	Energy for beamforming



PT TAJUK HUMAN  
PERPUSTAKAAN TUNKU TUN AMINAH

## **CHAPTER 1**

### **INTRODUCTION**

In late years, Wireless Sensor Network (WSN) has evolved worldwide attention due to the importance of monitoring in hazardous environment. The development of WSN has its origins in military research and applications in monitoring the conflict area. Today, they are widely applied in environmental monitoring and protection of nature and humanity. More applications are monitoring the widespread fire, check the level of water and air pollution in an industry, atmospheric collection of information (humidity, press) and monitoring wildlife protected areas.

In this chapter discusses the background of the research. In addition, the objectives of project, problem statement and scopes of study.

#### **1.1 Background of Project**

##### **1.1.1 Overview**

Wireless Sensor Networks can be defined as a self-configured and infrastructure-less Wireless networks to monitor physical or environmental conditions, such as temperature, sound, vibration, force per unit area, motion or pollutants and to cooperatively pass their information through the network to a main location or sink where the data can be noted and analysed. A sink or base station works like an interface between users and the mesh. One can retrieve required information from the network by injecting queries and gathering results from the sink. Typically a wireless sensor network contains hundreds of thousands of sensor nodes. The sensor nodes can pass among themselves using radio signals. A wireless sensor node is equipped with sensing and computing devices, wireless transceivers and power factors. The

individual nodes in a wireless sensor network (WSN) are inherently resource constrained: they have limited processing speed, memory capability, and communication bandwidth. Later on the sensor nodes are deployed, they are responsible for self-organizing an appropriate network infrastructure often with multi-hop communication with them. Then the on-board sensors start collecting information of interest. Wireless sensor devices also respond to queries sent from a “control site” to perform specific instructions or provide sensing samples. The running mode of the sensor nodes may be either continuous or event driven. Global Positioning System (GPS) and local positioning algorithms can be applied to get the location and placement data. Wireless sensor devices can be fitted with actuators to “act” upon certain conditions.

WSNs applications are applied to perform many vital jobs, including medical monitoring, natural event monitoring, target tracking, monitoring product quality, combat field reconnaissance, and military command and command. Properties that such applications must have include availability, dependability, safety and protection. The impression of dependability captures these concerns within a single conceptual framework, making it possible to approach the different requirements of a critical system in a unified manner. Alike to other computing areas, sensor network computing systems are characterized by four fundamental properties: functionality, functioning, cost and reliability. Dependability of a system is the ability to deliver services that can justifiably be trusted. The feeling of dependability is broken down into six fundamental properties: (1) reliability, (2) availability, (3) safety, (4) confidentiality, (5) integrity and (6) maintainability. Informally, it is expected that a dependable system will be operational when needed (availability), that the system will keep operating correctly while being used (reliability), that there will be no unauthorized disclosure (confidentiality) or modification of information that the system is using (Integrity) and that operation of the system will not be dangerous (safety).

### 1.1.2 Introduction of WSNs logical topologies

In Wireless Sensor Networks (WSNs), topology plays an essential part in minimizing different imperatives, for example, latency, restricted vitality, computational asset emergency, and nature of the correspondence. Case in point, energy utilization is corresponding to the quantity of bundles sent or got. The getting expense relies on upon packet size, while the transmission vitality relies on upon the separation between the nodes. As topology innately characterizes the sort of steering ways, demonstrates whether to utilize show or unicast, decides the sizes and sorts of parcels and different overheads, picking the right topology serves to diminish the amount of communication required for a specific issue and in and thus save energy. An effective topology, which guarantees that neighbors are at a negligible distance, diminishes the likelihood of a message being lost between sensors. A topology can likewise lessen the radio interference, thus decreasing the holding up time for the sensors transmit information. In addition, topology facilitates information accumulation, which significantly diminishes the measure of transforming cycles and vitality, accordingly giving a more drawn out the lifetime of the system. What's more, topology naturally characterizes the extent of a gathering, how to oversee new parts in a gathering, or how to manage parts that have left the gathering. With the consciousness of the fundamental system topology, more proficient steering or broadcasting schemes can be accomplished. Besides, the system topology in WSNs can be changed by fluctuating the nodes transmitting ranges furthermore by confirming the wake/sleep schedule of the nodes. In this manner, more energy can be saved if the system topology is kept up in an ideal way (Mamun, 2012).

## 1.2 Problem statements

The wireless sensor networks have constrained in transforming and storage, the most difficulties in wireless sensor networks are energy dissipation, system life time and throughput, where the energy consumption is relative to the quantity of packets sent or got. The getting expense relies on upon packet size, while the transmission energy relies on upon the distance between the nodes, the lifetime of a sensor system is most usually characterized as the time from the moment the system begins working for the first sensor node loser. However, this definition appears to be excessively negative

for WSNs, since the loser of one node does not keep whatever is left of the node from giving proper usefulness because of the repetition of sent nodes, and the sorting toward oneself out and issue tolerance abilities of WSNs. The discussions above derive that logic topologies play the most significant part in the general performance of the networks, including its lifetime, energy dissipation and amount data received. Hence, by executing some experiments for assessment of different logical topologies with their corresponding protocols can choose the better topology designing routing protocols / algorithms for WSNs.

### **1.3 Project objectives**

The objectives of this project are:

1. To identify various logical topologies from different application protocols WSNs
2. To perform various simulations for a set of different topologies.
3. To evaluate the performance of the different topologies using a set of performance metrics.

### **1.4 Project scopes**

This project is concerned with the scopes as follows:

1. Study the flat, cluster-distributed, cluster-centralization, and chain logical topologies along with their corresponding routing protocols.
2. Evaluative study of the impact of some parameters on the efficiency of the performance of WSNs.
3. The performance comparison of these logical topologies using their particular routing protocols against a set of performance metrics, including energy consumption, network lifetime, and aggregate data received at the base station.
4. The network simulation (NS-2.34) program used to study and analysis the different logical topologies.



## 1.5 Thesis structure outline

This thesis is a documentary to deliver the generated idea, the concepts applied, the activities done, and finally, the project product produced. This thesis consists of five chapters.

Chapter 1 discusses the background of the research. In addition, the problem statement, objectives of project, scopes of study and thesis structure outline are presented.

Chapter 2 contains literature review discussing the application of WSNs, the various logic topologies for wireless sensor networks along with their corresponding routing protocols, energy radio model and performance metrics. In addition, the simulation program (NS-2.34) and Matlab also discussed.

Chapter 3 argue about the way that used to improve the project, including the tools, equipment's, procedures and processes involved in the software improvement and accomplishment of the project. In addition, the flowchart of study, the system model assumption is presented.

Chapter 4 discusses about the simulation model parameters and the results for the experiments reported for evaluated and analytically different logical topologies for WSNs as cluster –distributed, chain-based, cluster–centralized and flat with their corresponding protocols (LEACH, PEGASIS, LEACH-C and MTE), regarding of network lifetime, energy dissipation and aggregate data received at the base station . In addition, perform an important of those parameters of concerned (sensor filed size  $M \times M$ , initial energy, numbers of nodes, optimum number of clusters, and data packet size) on the proficiency WSNs by doing various scenarios are presented.

Finally, Chapter 5 covered the conclusions and proposals for future work. Important results and methodology, obtained from previous chapters were summarized, and the possibilities for future directions were discussed.

## CHAPTER 2

### LITERATURE REVIEW

This chapter summarizes the information of the related previous studies on WSNs. In addition, the chapter covers types of most WSN, the related topologies, routing protocols, performance metrics and the simulation environment. These reviews are done based on materials from journals, conference proceeding and books.

#### 2.1 Wireless Sensor Networks

##### 2.1.1 Overview of WSNs

A sensor network consists of a large number of sensor nodes that are deployed in a wide area with very low powered sensor nodes. The wireless sensor networks can be utilized as part of various information and telecommunications applications. The sensor nodes are very small devices with the capability of wireless communication, which collects information about sound, light, motion, temperature humanity and processed them before transferring it to the other nodes.

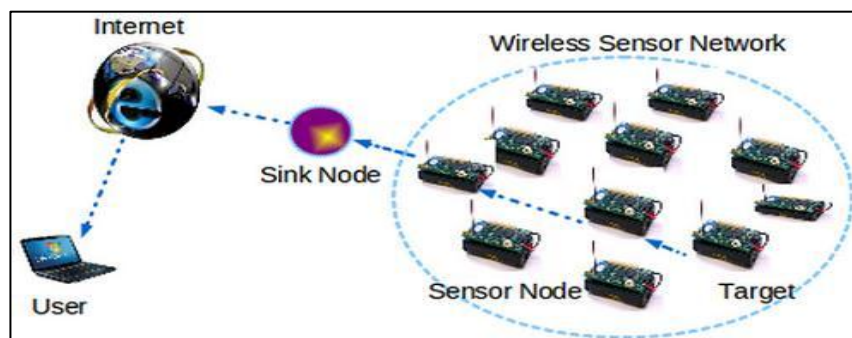


Figure 2.1: The Wireless Sensor Network scenario

### 2.1.2 Characteristics of Sensor Nodes

Wireless Sensor Networks are:

- (i). Self-configuration, Self-healing, Self -optimizing, and Self-protection.
- (ii). Capable of Short-range broadcasting communication and multi-hop routing.
- (iii). Dense deployment and cooperative effort of sensor nodes.
- (iv). Frequently changing topology due to fading and node failures.
- (v). Severe limitations in energy capacity, computing power, memory, and transmitting power.

### 2.1.3 Sensor node architecture

A wireless sensor node is composed of four basic components, namely sensing unit, processing unit (microcontroller), transceiver unit and power unit.

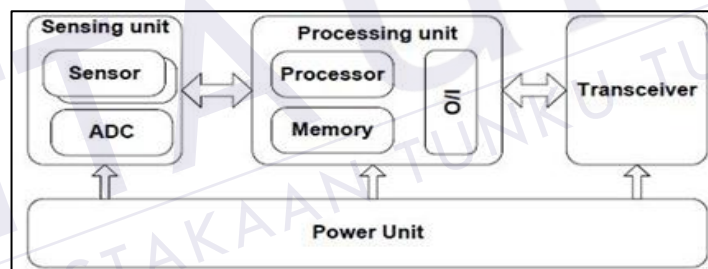


Figure 2.2: Architecture of a typical sensor node

Figure 2.2 shows the typical construction of a sensor node. In addition to the above units, a wireless sensor node may include a number of application-specific components, for example, a location detection system or mobilizer. For this reason, many commercial sensor node products include expansion slots and support serial wired communication. Descriptions of the basic components are given below:

- **Sensing Unit:** A sensor is a device that measures some physical quantity and converts it into a signal to be processed by the microcontroller. A wide range of sensor types exists, including seismic, thermal, acoustic, visual, infrared and magnetic. Sensors may be passive (sensing without active manipulation of the environment) or active (using active manipulation/probing of the

environment to sense data, e.g. radar) and may be directional or omnidirectional. A wireless sensor node may include multiple sensors providing complementary data. The sensing of a physical quantity such as those described, typically resulted in the production of a continuous analogue signal. For this reason, the sending unit is typically composed of a number of sensors and an analogue to digital converter (ADC) which digitizes the signal.

- **Microcontroller:** A microcontroller provides the processing power for, and coordinates the activity of, a wireless sensor node. Unlike the processing units associated with larger computers, a microcontroller integrates processing with some memory provision and I/O peripherals. Such integration reduces the need for additional hardware, wiring, energy and circuit board space. In addition to the memory provided by the microcontroller, it is not uncommon for a sensor node to include some external memory, for example, in the form of flash memory.
- **Transceiver:** A transceiver unit allows the transmission and reception of data to other devices connecting a wireless sensor node to a network. Wireless sensor nodes typically communicate using an RF (radio frequency) transceiver and a wireless personal area network technology such as Bluetooth or the 802.15.4 compliant protocols ZigBee and MiWi. The 802.15.4 standard specifies the physical layer and medium access control for low-rate, low-cost wireless communications, whilst protocols such as ZigBee and MiWi build upon this by developing the upper layers of the OSI Reference Model. The Bluetooth specification crosses all layers of the OSI Reference Model and is also designed for low-rate, low-cost wireless networking.
- **Power Source.** All wireless sensor nodes must be supported by a power unit which is typically some form of storage (that is, a battery) but may be supported by power scavenging components (for example, solar cells). Energy from power scavenging techniques may only be stored in rechargeable (secondary) batteries and this can be a useful combination in wireless sensor node environments where maintenance operations like battery changing is impractical. To conserve energy, a power unit may additionally support power conservation techniques such as dynamic voltage scaling.

Wireless sensor networking has such sensor nodes, which are especially designed in such a typical way that they have a microcontroller which controls the monitoring, a radio transceiver for generating radio waves, and different types of wireless communicating devices and also ready with an energy source like a battery. The entire network worked simultaneously by using different dimensions of sensors and worked on the phenomenon of multi routing algorithm which is also termed as wireless ad hoc networking.

#### **2.1.4 Types of Wireless Sensor Networks**

Wireless sensor networks are deployed on land, underground, and underwater. A sensor network faces different challenges and constraints according to the environment in the sensor network deployed. There are five types of the wireless sensor network as discussed in (Yick, Mukherjee and Ghosal, 2008).

- (i). Terrestrial Wireless sensor network.
- (ii). Underground Wireless sensor network.
- (iii). Underwater Wireless sensor network.
- (iv). Multimedia Wireless sensor network.
- (v). Mobile Wireless sensor network.

#### **2.1.5 Wireless Sensor Network Applications**

Wireless sensor network has a lot of applications like security, monitoring, biomedical research, tracking, etc. Basically, these applications are very useful for emergency services. Sensor network is categorized into various classes such as Environmental data collection, military applications, security monitoring, sensor node tracking, health application, home application, and hybrid networks.

### **2.2 WSNs Challenges and Constraints**

In order to design a better protocol, or algorithm, for WSN operation, it is necessary to first clearly understand the challenges and constraints. These challenges and Constraints are summarized by (Mamun, 2012) as the following: (i) Limited energy; (II) Low-quality communications; (iii) Resource- constrained computation; (iv)

Data processing; (v) Scalability; (vi) Reliability; (vii) Responsiveness; (viii) Mobility; (ix) Power Efficiency; (x) Managing the design tradeoffs.

### **2.2.1 Limited energy**

Reducing node energy consumption is vital in WSNs. In fact, because of the reduced size of the sensor nodes, the battery has low capacity, and the available energy is very limited. Despite this scarcity of energy, the network is expected to operate for a relatively long time. Given that replacing batteries are usually impossible, one of the primary design goals is to use this limited amount of energy as efficiently as possible.

### **2.2.2 Low-quality communications**

Wireless communications are always less reliable and have less quality compared to wired communication. Besides, sensor networks are often deployed in harsh environments, and sometimes they operate under extreme weather conditions. In these situations, the quality of the radio communication might be extremely poor, and performing the requested collective sensing task might become very difficult.

### **2.2.3 Resource- constrained computation.**

The resources are scarce in WSNs. Protocols for sensor networks must strive to provide the desired quality of service (QOS) in spite of the few available resources.

### **2.2.4 Data processing**

Given the energy constraints, and the relatively poor communication quality, the data collected by the sensor node must be locally compressed and aggregated with similar data generated by the neighboring nodes. This way, relatively fewer resources are used to communicate the data to the external observer.

### 2.2.5 Scalability

Scalability refers to the ability of the network to grow, in terms of the number of nodes, without excessive overhead. This is an important real world requirement, where networks must support more than the small handful of nodes typically in a pilot implementation. This is due to the network overhead that comes with the increased size of the network. In ad hoc networks, the network is formed without any predetermined topology or shape. Therefore, any node wishing to communicate with other nodes should generate more packets than its data packets, i.e., control packets or network overhead. As the size of the network grows, more control packets will be needed to find and keep the routing paths. Moreover, as the network size increases, there is a higher chance that communication links become broken in communication paths, which will end up creating more control packets. In a small network, the amount of control packets is almost negligible. However, when the network size starts increasing, the overhead increases rapidly. Since the available overall bandwidth is limited, the increase of overhead results in the decrease of usable bandwidth for data transmission. As the network size grows further, there is a very small amount of bandwidth left for application data transmission.

### 2.2.6 Reliability

Reliability is the ability of the network to ensure reliable data transmission in a state of continuous change of network structure. Typically, there is an inverse relationship between scalability and reliability in ad hoc wireless networks. As the number of nodes in the network increases, the more difficult it becomes to ensure reliability. This scalability characteristic of ad hoc networks described earlier imposes an interesting question about the reliability of the network. Since an ad hoc network is designed to automatically adapt itself to a changing environment or interference, it will issue more control packets dynamically. More dynamics in the environment will increase the number of control packets, and at some point, the network cannot sustain the amount of overhead caused by the dynamics, which will result in less reliability of data transmission. This breaking point will show up earlier in a large-sized network compared to a small or medium sized network. Thus, network scalability



and reliability are closely coupled, and typically, they act against each other.

### **2.2.7 Responsiveness**

Responsiveness is the ability of the network to quickly adapt itself to changes in topology. High responsiveness can achieve in an ad hoc network, where the system issues more control packets, which will naturally result in less scalability and less reliability.

### **2.2.8 Mobility**

Mobility refers to the ability of the network to handle mobile nodes and changeable data paths. Generally, a wireless sensor network that includes a number of mobile nodes should have high responsiveness to deal with the mobility. Therefore, it is not easy to design a large scale and highly mobile wireless sensor network.

### **2.2.9 Power Efficiency**

Power efficiency, the ability of the network to operate at extremely low power levels, also plays an important role. A typical method for designing a low-power wireless sensor network is to reduce the duty cycle of each node. The drawback is that as the wireless sensor node stays longer in sleep mode to save power, there is less chance that the node can communicate with its neighbor's. This decreases the network responsiveness, and also lowers reliability due to the lack of the exchange of control packets and delays in packet delivery. In addition, a more complicated synchronization technique will be necessary to keep more nodes in low duty cycle, which may also affect scalability.

### **2.2.10 Managing The Design Tradeoffs**

The complex issue of managing these tradeoffs comes down to how the communication overhead can be minimized while maintaining the network reliability and responsiveness. As explained earlier, there are many conflicting factors involved



in the design of wireless sensor networks, and there are always design tradeoffs. When choosing a wireless sensor network for an application, careful consideration of the balance of these factors within the context of the needs of the application is critical.

## **2.3 Wireless Sensor Networks Logical Topologies**

In Wireless Sensor Networks (WSNs), topology plays an essential part in minimizing different imperatives, for example, latency, restricted vitality, computational asset emergency and nature of the correspondence.

### **2.3.1 Flat Logical Topology**

This is actually no topology, or the absence of any defined topology. In flat topology, each sensor plays an equal role in network formation. Different protocols have been proposed based on flat/unstructured topology (Mamun, 2012). For example, this flat topology has been used in data aggregation protocols (Xu and Wang, 2011), data gathering protocols (Fan and Sinha, 2007), node scheduling protocols (Sausen and Perkusichy, 2008), and routing protocols (Hussain and Islam, 2007). Figure 2.3 shows the flat topology architecture where the nodes are the sensors and the edges are available communication links between two sensors.

All the protocols, while using flat topology, attempt to find good-quality routes from source nodes to sink nodes by some form of flooding. Flooding is a technique in which a given node broadcasts received data and control packets to the rest of the nodes in the network. This process repeats until the destination node is reached. Note that this technique does not take into account the energy constraints imposed by the WSNs. As a result, when used for data routing in WSNs, it leads to two problems, namely, implosion and overlap (Heinzelman and Balakrishnan, 1999). Given that flooding is a blind technique, duplicate packets may keep circulating in the network, and hence sensors will receive those duplicate packets, causing an implosion problem. In addition, when two sensors sense the same region and broadcast their sensed data at the same time, their neighbor's will receive duplicate packets.

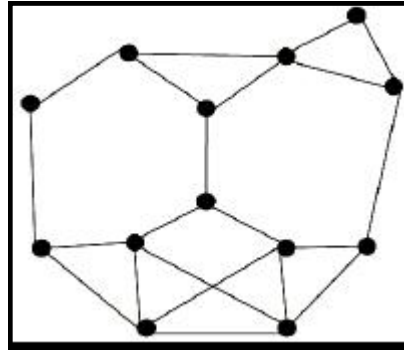


Figure 2.3: Flat logical topology (Mamun, 2012)

In a flat network, data aggregation is accomplished by data-centric routing where the BS usually transmits a query message to the sensor nodes via flooding, and the sensor nodes that have data matching in the query, will send response messages back to the BS. The sensor nodes communicate with the BS via multi-hop routes by using peer nodes as relays. The choice of particular communication protocol depends on a specific application.

### 2.3.2 Cluster Logical Topology

In general, when working with clusters it is possible to identify three main elements in the WSN: sensor nodes (SNs), base station (BS) and cluster heads (CH) (see Figure 2.4). The SNs are the set of sensors present in the network, arranged to sense the environment and collect the data. The main task of a SN in a sensor field is to detect events, perform quick local data processing, and then transmit the data. The BS is the data processing point for the data received from the sensor nodes, and where the data is accessed by the end-user.

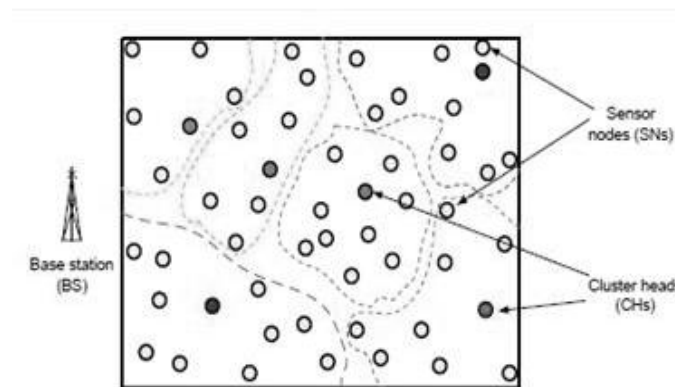


Figure 2.4: Cluster Logical topology (Mamun, 2012)

It is generally considered fixed and at a far distance from the sensor nodes. The CH acts as a gateway between the SNs and the BS. The function of the cluster head is to perform common functions for all the nodes in the cluster, like aggregating the data before sending it to the BS. In some way, the CH is the sink for the cluster nodes, and the BS is the sink for the cluster heads. This structure is formed among the sensor nodes, the sink and the BS and is replicated as many times as it is needed, creating the different layers of the hierarchical WSN. The greatest constraint, it has is the power consumption, which usually is caused when the sensor is observing its surroundings, and communicating (sending and receiving) data.

### 2.3.2.1 Cluster Types

Clustering algorithms can be classified as Distributed Clustering and Centralized Clustering. Distributed clustering techniques are further classified into four sub types based on the cluster formation criteria and parameters used for CH election as based on identity, neighbourhood information, Probabilistic, and Iterative respectively (Geetha and Tellajeera, 2012).

### 2.3.3 Chain Logical Topology

Chain oriented topologies have been used by researchers in designing various protocols, among which data broadcasting protocols, data collection/gathering protocols and routing protocols are the major instances. Chain topologies are mainly used in these protocols to reduce the total energy consumption, and thus to increase the lifetime of the network.

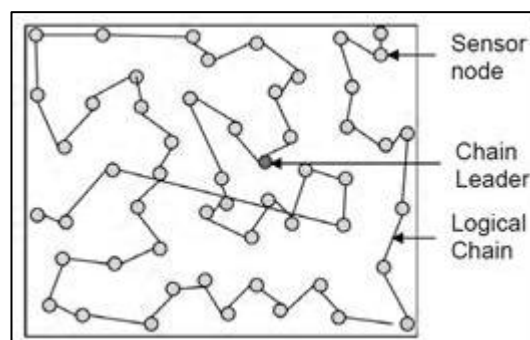


Figure 2.5: Chain Logical topology (Mamun, 2012)

## 2.4 Protocols of WSNs

When designing network protocols for wireless sensor networks, several factors should be considered. First and foremost, because of the scarce energy resources, routing decisions should be guided by some awareness of the energy resources in the network. Furthermore, sensor networks are unique from general ad hoc networks in that communication channel often exist between events and sinks, rather than between individual source nodes and sinks.

### 2.4.1 Low-Energy Adaptive Clustering Hierarchy (LEACH) Protocol

LEACH is a type of cluster-based routing protocols, which utilizes a distributed cluster formation. LEACH arbitrarily chooses a couple of sensor nodes as cluster heads (CHs) and turns this part to equitably circulate the energy load among the sensors in the system. The idea is to structure. And cluster the sensor nodes focused around those nodes that have signal quality and use neighborhood group heads as switches to the sink (Sharma and Verma, 2013). In LEACH, the Cluster Heads clamp information received all members of the cluster and send the collected packet to the base station keeping in mind the end goal to lessen the amount of data that must be transmitted to the BS. With a specific goal to diminish inter and intra - cluster obstruction LEACH utilizes a TDMA/code-division to ensure successful access (CDMA) to MAC. The operation of LEACH is carried out in two steps. The setup stage and the steady state. In setup stage the nodes are composed into clusters and CHs are chosen. These cluster heads change haphazardly about whether to keep in mind the goal to adjust the vitality of the system. This is carried out by picking an irregular number somewhere around 0 and 1 (Thakkar and Kotecha, 2014). The node is chosen as a CH for the present round if the random number is short of what the threshold value  $T(n)$ , which is given by

$$T(n) = \begin{cases} \frac{p}{1 - p * (r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{Otherwise} \end{cases} \quad (2.1)$$

where

$p$  - is the Cluster head probability,

$r$  - is the Current round number and

$G$  - is the Group of nodes that have not been cluster head in the last  $1/p$  rounds.

Here  $G$  is the number of nodes that are included in the previous round of CH elections. LEACH clustering is shown in Figure 2.6. In the steady state stage, the genuine information is exchanged to the base station. In order to minimize overhead the time of the steady state stage ought to be longer than the length of time on the setup stage. The CH node, in the wake of accepting all the information from its path nodes, has performed data collection before sending it to the base station. After a certain time period, the setup stage is restarted and new CHs are chosen. Each cluster communicates utilizing different CDMA codes to lessen impedance from nodes fitting in with different clusters. The strategies to accomplish the objectives of these are as follows:

- Randomized, versatile, outlining toward oneself group development.
- Localized control of information exchanges.
- Low vitality media access control (MAC).
- Application of particular information processing, for example, information accumulation and compression.

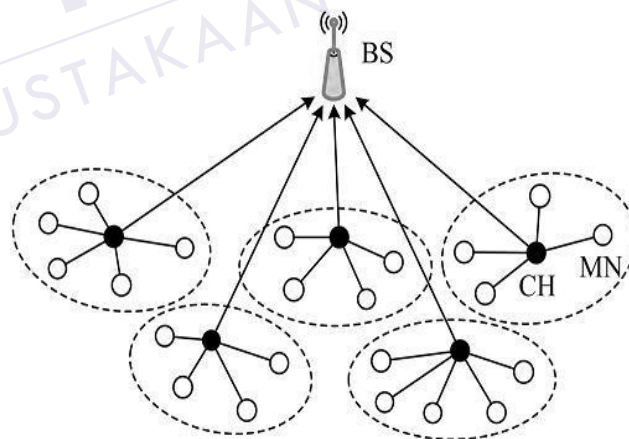


Figure 2.6: cluster head selection (Liu, 2012)

#### 2.4.1.1 Operation of the LEACH

The operation of LEACH is divided into two phases, where the stages of the setup Phase (where cluster-heads are chosen):

- Cluster-head Advertisement.
- Cluster Set-Up.
- Transmission schedule creation.

And the stages of the steady state Phase (The cluster-head is maintained when data is transmitted between nodes):

- Data transmission to cluster heads.
- Signal processing (Data fusion).
- Data transmission to the base station.

#### 2.4.1.2 Cluster Head (CH) selection

For the selecting of the clusters-head nodes (Heinzelman, 2000)

- $P_i(t)$  is the probability with which node  $i$  elects it to be (CH) at the beginning of the round  $r+1$  (which starts at time  $t$ ) such that the expected number of clusters-head nodes for this round is  $k$ .

$$E[\#CH] = \sum_{i=1}^N P_i(t) * 1 = k. \quad (2.2)$$

where

$N$  is the number of sensor nodes,

$P_i(t)$  is the probability with which node  $i$  elects it to be (CH),

$k$  is the expected number of clusters-head.

- Each node will be cluster head once in  $\frac{N}{k}$  rounds.
- Probability for each node  $i$  to be a cluster-head at time  $t$ ,  $C_i(t) = i_t$  determines whether node  $i$  has been a cluster head in most recent  $(r \bmod (N/k))$  rounds .

$$P_i(t) = \begin{cases} \frac{k}{N - k * (r \bmod \frac{N}{k})} & C_i(t) = 1 \\ 0 & C_i(t) = 0 \end{cases} \quad (2.3)$$

$$\left[ \sum_{i=1}^N C_i(t) \right] = N - k * \left( r \bmod \frac{N}{k} \right) \quad (2.4)$$

$\sum_{i=1}^N C_i(t)$  = Total no. of nodes eligible to be a cluster – head at time t.

This ensures energy at each node to be approximately equal after every  $\frac{N}{k}$  round. Using (2.3) and (2.4), the expected number of Cluster Heads per round is,

$$\begin{aligned} E[\#CH] &= \sum_{i=1}^N P_i(t) * 1 \\ &= \left( N - k * \left( r \bmod \frac{N}{k} \right) \right) * \frac{k}{N - k * \left( r \bmod \frac{N}{k} \right)} \\ &= k. \end{aligned}$$

#### 2.4.1.3 Cluster Formation Algorithm

The cluster formation and the cluster head selection algorithm are given below:

- **Step1:** Initialization
- **Step2:** if node i is CH processed from step3 to step7. If not returns to step1.
- **Step3:** CH broadcasts an advertisement message (ADV) using the CSMA MAC protocol. ADV = node's ID + distinguishable header.
- **Step4:** Based on the received signal strength of ADV message, each non-Cluster Head node determines it's Cluster Head for this round.
- **Step5:** Each non-Cluster Head transmits a join-request message (Join-REQ) back to its chosen Cluster Head using a CSMA MAC protocol. Join-REQ = node's ID + cluster-head ID + header.
- **Step6:** Cluster Head node sets up a TDMA schedule for data transmission coordination within the cluster.
- **Step7:** TDMA Schedule (1. Prevents collision among data messages. 2. Energy conservation in non-cluster-head nodes).
- **Step8:** End.



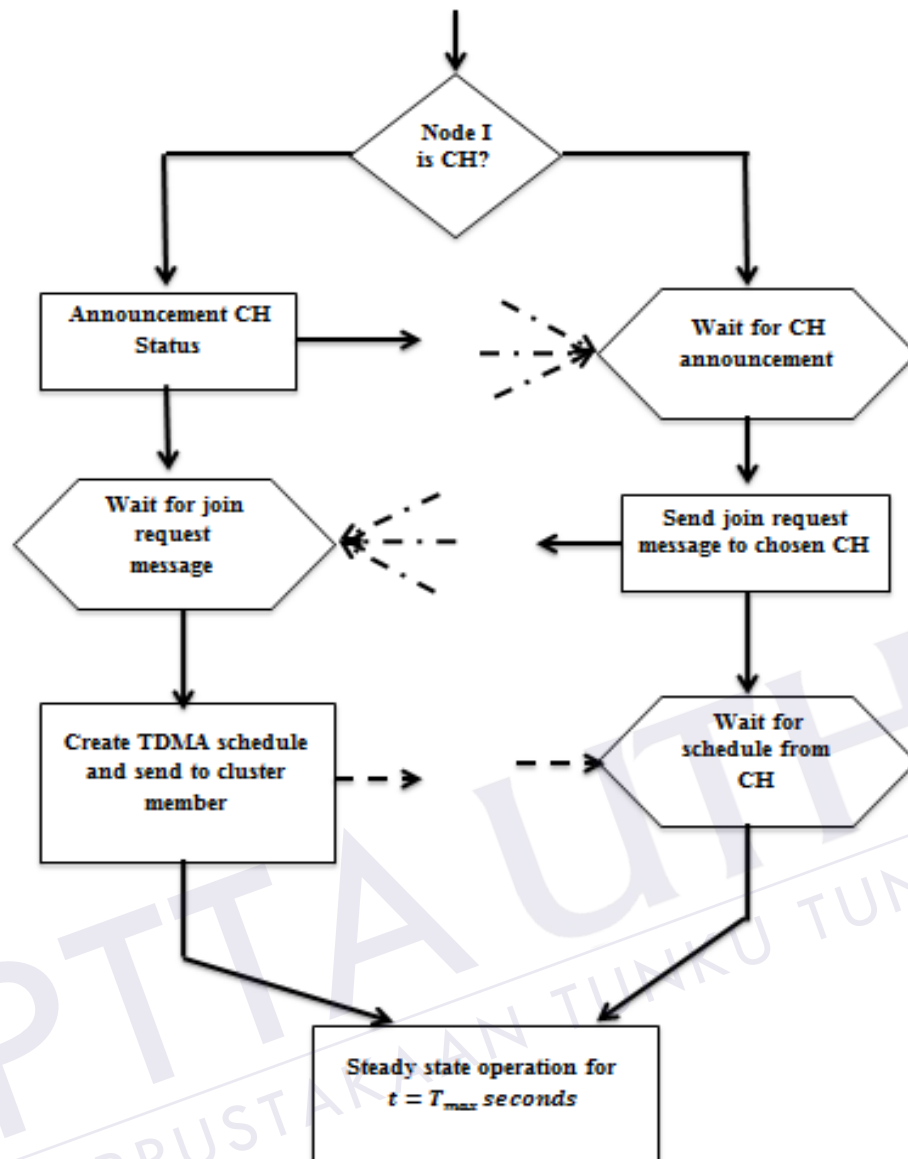


Figure 2.7: Distributed cluster formation algorithm (Heinzelman, 2000)

#### 2.4.1.4 Sensor Data Aggregation

Sensor data are not quite the same as the data connected with conventional wireless networks in that it is not the genuine data itself that is critical; rather, the investigation of the information, which permits an end-client to determine something about the environment that is, no doubt checked, is the essential result of a sensor network. Consider a case where the sensors are monitoring an area for surveillance purposes, the end-client does not have to see the data from all the individual sensors, however, it is needed to know whether there has been an interruption in the region



being observed. Therefore, mechanized routines for consolidating the data into a little set of compounded data are needed. In addition to helping avoid data overburden, data aggregation, otherwise called data fusion, can consolidate a few untrustworthy data estimations to create a more accurate signal by improving the regular signal and lessening the uncorrelated noise. The manipulation performed on the collected data may be performed by a human administrator or off-hand (automatically). The method of performing data aggregation and the classification algorithm are application-specific. (Heinzelman, 2000).

In a routine sensor network, all the data  $x$  are transmitted to the base station, where they are aggregated to obtain the data  $F(x)$ . Automated strategies can then be used to characterize this aggregate signal (e.g., based on template source signatures). However, the function  $f$  can sometimes be broken up into several smaller functions  $f_1, f_2, \dots, f_n$  that operate on subsets of the data  $X_1, X_2, \dots, X_n$  such that:

$$f(X) \approx g(f_1(X_1), f_2(X_2), \dots, f_n(X_n)) \quad (2.5)$$

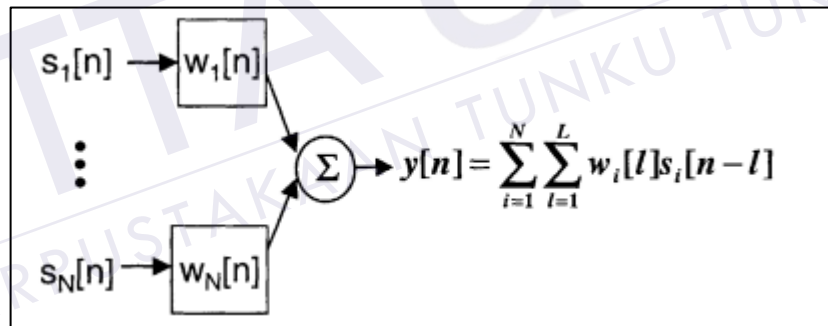


Figure 2.8: Block diagram of the Beamforming algorithm

The capability to break the function in this way preempts the possibility of the sensor nodes performing a local calculation on a subset of the information. This can enormously decrease the amount of data that needs to be transmitted to an end-client. In the event that the energy needed to perform the signal processing functions is short compared to the energy needed to transmit the starting information, energy investment is achieved. One method of aggregating data is called Beamforming. Beamforming combines signals from multiple sensors as follows:

$$y[n] = \sum_{i=1}^N \sum_{j=1}^L w_i[L] s_i[n - 1] \quad (2.6)$$

where

$s_i[n]$  - is the signal from the  $i^{\text{th}}$  sensor,

$w_i[L]$  - is the weighting filter for the  $i^{\text{th}}$  signal,

$N$  - is the total number of sensors, whose signals are being beamformed,

$L$  - is the number of taps in the filter.

This algorithm is depicted in Figure 2.8. The weighting filters are chosen to satisfy optimization criteria, such as minimizing the mean squared error (MSE) or maximizing signal-to noise ratio (SNR). Various algorithms, such as least mean squared (LMS) error approach and the maximum power beamforming algorithm have been developed to determine good weighting filters. These algorithms have various energy and quality tradeoffs. For example, the maximum power beamforming algorithm is capable of performing blind beamforming, requiring no information about the sensor locations. However, this algorithm computation intensive, which will quickly drain the limited energy of the node. By determining the amount of computation needed to fuse the data from several sensor nodes and the associated energy and time costs to perform these signal processing operations, it is possible to determine the optimum tradeoff between computation and communication. For example, determine the optimal number of sensors to utilize in processing data to minimize the overall time until the solution is achieved given a simple line network. In general networks, there is no closed-form solution as there is in a linear network, but heuristics can be developed to achieve good tradeoffs between computation and communication.

The previous section described the need to aggregate sensor data to produce a meaningful description of events that are occurring in the environment. Data aggregation can be performed on all the unprocessed data at the base station or it can be performed locally on the cluster-heads. If the energy for communication is greater than the energy for computation, performing data aggregation locally at the cluster-head can reduce the overall system energy consumption, since much less data needs to be transmitted to the base station. This will allow large computation versus communication, energy gains with little to no loss in overall network quality.

The energy dissipation for local data aggregation and provender of sending the aggregate data can be analytically compared. Suppose that the energy dissipation per bit for data aggregation is  $E_{DA}$  and the energy dissipation per bit to transmit to the base station is  $E_{TX}$ . In addition, suppose that the data aggregation method can compress the data with a ratio of  $L:1$ . This means that for every  $L$  bits that must be sent to the base station when no data aggregation is performed, only 1 bit must be sent to the base station when local data aggregation is performed. Therefore, the energy to perform local data aggregation and transmit the aggregate signal for every  $L$  bits of data is:

$$E_{Local-DA} = LE_{DA} + E_{TX} \quad (2.7)$$

and the energy to transmit all  $L$  bits of data directly to the base station is:

$$E_{No-DA} = LE_{TX} \quad (2.8)$$

Therefore, performing local data aggregation requires less energy than sending all the unprocessed data to the base station when:

$$\begin{aligned} E_{Local-DA} &< E_{No-DA} \\ LE_{DA} + E_{TX} &< LE_{TX} \\ E_{DA} &< \frac{L-1}{L} E_{TX} \end{aligned} \quad (2.9)$$

where

$E_{DA}$ - is the energy dissipation per bit for data aggregation,

$E_{TX}$ - is the energy dissipation per bit to transmit to the base station,

$L$ - is the data (bits) to transmit.

#### 2.4.2 Power-efficient gathering in sensor information systems (PEGASIS) protocol

PEGASIS is an essential chain directing protocol (Lindsey and Sivalingam, 2002). In which, all nodes in the sensing territory are initially sorted out into a chain by utilizing a greedy algorithm, and after that alternate to go about as the chain pioneer. In information spread stage, each node gets the sensing data from its closest upstream neighbor, and afterward passes its collected information on the assigned pioneer, by means of its downstream neighbor, lastly the base station. Despite the

fact that the PEGASIS develops a tie associating all nodes to adjust system vitality scattering, there are still a few issues with this scheme.

- For a substantial sensing field and ongoing applications, the single long chain may present an unsuitable information deferral time.
- Since the chain pioneer is chosen by alternating, for a few cases, a few sensor nodes might reversely their amassed information to the assigned pioneer, which is far from the base station than itself. This will bring about excess transmission ways, and hence truly waste system energy.
- The single chain leader may become a bottleneck.

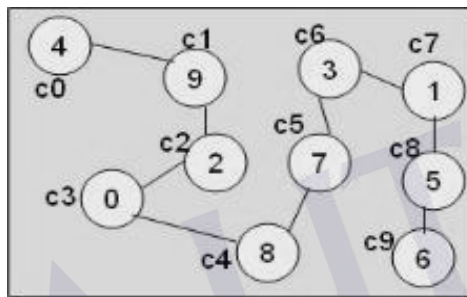


Figure 2.9: Example for PEGASIS Chain

As shows in above Figure 2.9, amid each round, a pioneer node is arbitrarily chosen. The pioneer node is in charge of sending the accumulated information to the sink. Once the pioneer node is chosen and told by the sink node, every node on both sides of the bind (as for the pioneer node), goats and transmits the accumulated information to the following node in the chain, until the information achieves the pioneer node. For instance, consider the chain framed in Figure 2.9 for a 10-node system. The list of the nodes in the chain is different from the recognizable proof numbers for the nodes (i.e., the node ID). In the event that node 3 at chain record 6 is chosen as the pioneer node, the stream of information would be in the accompanying request: c0 -7 c1 -7 c2 -7 c3 -7 c4 -7 c5 -7 c6 PEGASIS can prompt critical defers in information collection in view of the holding up time at the pioneer node to get information from both sides of the chain.

#### 2.4.2.1 Leader Selection

- **A random determination:** At the start of each round, a chain pioneer is

## REFERENCES

- Akyildiz, I.F., Su, W., Sankarasubramaniam, Y. & Cayirci, E. (2002). Wireless sensor networks: a survey. *Computer networks*, 38(4), pp. 393–422.
- Ali, S.A. & Refaay, S.K. (2011). Chain-chain based routing protocol. *International Journal of Computer Science Issues (IJCSI)*, 8(3).
- Aliouat, Z., & Aliouat, M. (2012, March). Efficient management of energy budget for PEGASIS routing protocol. In *Sciences of Electronics, Technologies of Information and Telecommunications (SETIT)*, 2012 6th International Conference on (pp. 516-521). IEEE.
- Al-Karaki, J.N. & Kamal, A.E. (2004). Routing techniques in wireless sensor networks: a survey. *Wireless communications, IEEE*, 11(6), pp. 6–28.
- Amis, A.D., Prakash, R., Vuong, T.H. & Huynh, D.T. (2000). Max-min d-cluster formation in wireless ad hoc networks. In: *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, volume 1, IEEE, pp. 32–41.
- Chatterjee, M., Das, S.K. & Turgut, D. (2002). Wca: A weighted clustering algorithm for mobile ad hoc networks. *Cluster Computing*, 5(2), pp. 193–204.
- Chen, Y., Liestman, A.L. & Liu, J. (2006). A hierarchical energy-efficient framework for data aggregation in wireless sensor networks. *Vehicular Technology, IEEE Transactions on*, 55(3), pp. 789–796.
- Cody-Kenny, B., Guerin, D., Ennis, D., Simon Carbajo, R., Huggard, M. & McGoldrick, C. (2009). Performance evaluation of the 6lowpan protocol on micaz and telosb motes. In: *Proceedings of the 4th ACM workshop on Performance*

monitoring and measurement of heterogeneous wireless and wired networks, ACM, pp. 25–30.

Dave, P. M., & Dalal, P. D. (2013). Simulation & Performance Evaluation of Routing Protocols in Wireless Sensor Network. *Simulation*, 2(3).

Fan, K.W., Liu, S. & Sinha, P. (2007). Structure-free data aggregation in sensor networks. *Mobile Computing, IEEE Transactions on*, 6(8), pp. 929–942.

Furuta, T., Sasaki, M., Ishizaki, F., Suzuki, A. & Miyazawa, H. (2007). A New Clustering Algorithm Using Facility Location Theory for Wireless Sensor Networks. Technical report, Technical Report NANZAN-TR-2006-04, Nanzan Aca-demic Society.

Geetha, V., Kallapur, P. & Tellajeera, S. (2012). Clustering in wireless sensor networks: Performance comparison of leach & leach-c protocols using ns2. *Procedia Technology*, 4, pp. 163–170.

Ghaffarzadeh, H., & Doustmohammadi, A. (2014). Two-phase data traffic optimization of wireless sensor networks for prolonging network lifetime. *Wireless networks*, 20(4), 671-679

Gnanasekaran, T., & Francis, S. A. J. (2014, January). Comparative analysis on routing protocols in Wireless Sensor Networks. In *Computer Communication and Informatics (ICCCI)*, 2014 International Conference on (pp. 1-6). IEEE.

Halgamuge, M., Zukerman, M., Ramamohanarao, K. and Vu, H. (2009). AN Estimation Of Sensor Energy Consumption. *PIER B*, 12, pp.259-295.

Haneef, M. (2012). Design Challenges and Comparative Analysis of Cluster Based Routing Protocols Used in Wireless Sensor Networks for Improving Network Life Time. *Advances in Information Sciences & Service Sciences*, 4(1).

Hani, R. and Ijeh, A. (2013). A Survey on LEACH-Based Energy Aware Protocols for Wireless Sensor Networks. *JCM*, 8(3), pp.192-206

Heinzelman, W.R., Chandrakasan, A. & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks. In: *System*

Sciences, 2000. Proceedings of the 33rd Annual Hawaii International Conference on, IEEE, pp. 10–pp.

Heinzelman, W.R., Kulik, J. & Balakrishnan, H. (1999). Adaptive protocols for information dissemination in wireless sensor networks. In: Proceedings of the 5th annual ACM/IEEE international conference on Mobile computing and networking, ACM, pp. 174–185.

Heinzelman, W. B. (2000). Application-specific protocol architectures for wireless networks (Doctoral dissertation, Massachusetts Institute of Technology).

Heinzelman, W. B., Chandrakasan, A. P., & Balakrishnan, H. (2002). An application-specific protocol architecture for wireless microsensor networks. *Wireless Communications, IEEE Transactions on*, 1(4), 660-670.

Hussain, S. & Islam, O. (2007). An energy efficient spanning tree based multi-hop routing in wireless sensor networks. In: *Wireless Communications and Networking Conference, 2007. WCNC 2007. IEEE*, IEEE, pp. 4383–4388.

Kumarawadu, P., Dechene, D.J., Luccini, M. & Sauer, A. (2008). Algorithms for node clustering in wireless sensor networks: A survey. In: *Information and Automation for Sustainability, 2008. ICIAFS 2008. 4th International Conference on*, IEEE, pp. 295–300.

Lindsey, S., Raghavendra, C. & Sivalingam, K.M. (2002). Data gathering algorithms in sensor networks using energy metrics. *Parallel and Distributed Systems, IEEE Transactions on*, 13(9), pp. 924–935.

Liu, X. (2012). A survey on clustering routing protocols in wireless sensor networks. *Sensors*, 12(8), pp. 11113–11153.

Loscri, V., Morabito, G. & Marano, S. (2005). A two-levels hierarchy for low-energy adaptive clustering hierarchy (tl-leach). In: *IEEE Vehicular Technology Conference*, volume 62, IEEE; 1999, p. 1809.

Mamun, Q. (2011). Constraint-Minimizing Logical Topology for Wireless Sensor Networks. Ph.D. thesis, Monash University.



Mamun, Q. (2012). A qualitative comparison of different logical topologies for wireless sensor networks. *Sensors*, 12(11), 14887-14913.

Manjeshwar, A. & Agrawal, D.P. (2001). Teen: A routing protocol for enhanced efficiency in wireless sensor networks. In: *IPDPS*, volume 1, p. 189.

Miller, M. J., & Vaidya, N. F. (2005). A MAC protocol to reduce sensor network energy consumption using a wakeup radio. *Mobile Computing, IEEE Transactions on*, 4(3), 228-242.

Sausen, P.S., Spohny, M. & Perkusichy, A. (2008). Energy efficient blind flooding in wireless sensors networks. In: *Industrial Electronics, 2008. IECON 2008. 34th Annual Conference of IEEE, IEEE*, pp. 1736–1741.

Sharma, N. & Verma, V. (2013). Energy efficient leach protocol for wireless sensor network. *International Journal of Information and Network Security (IJINS)*, 2(4), pp. 333–338.

Thakkar, A., & Kotecha, K. (2014). Alive Nodes Based Improved Low Energy Adaptive Clustering Hierarchy for Wireless Sensor Network. In *Advanced Computing, Networking and Informatics-Volume 2* (pp. 51-58). Springer International Publishing.

Wang, A. and Chandrakasan, A. (2002). Energy-efficient DSPs for wireless sensor networks. *IEEE Signal Process. Mag.*, 19(4), pp.68-78.

Wang, J., Tang, B., Zhang, Z., Shen, J., & Kim, J. U. (2014). An Energy Efficient Data Dissemination Algorithm for Wireless Sensor Networks. *PP*.1-6.

Xu, X., Li, M., Mao, X., Tang, S. & Wang, S. (2011). A delay-efficient algorithm for data aggregation in multihop wireless sensor networks. *Parallel and Distributed Systems, IEEE Transactions on*, 22(1), pp. 163–175.

Ye, M., Li, C., Chen, G. & Wu, J. (2005). Eecs: an energy efficient clustering scheme in wireless sensor networks. In: *Performance, Computing, and Communications Conference, 2005. IPCCC 2005. 24th IEEE International, IEEE*, pp. 535–540.



Yick, J., Mukherjee, B. & Ghosal, D. (2008). Wireless sensor network survey. *Computer networks*, 52(12), pp. 2292–2330.

Younis, O. & Fahmy, S. (2004). Heed: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. *Mobile Computing, IEEE Transactions on*, 3(4), pp. 366–379.

Yu, L., Wang, N., Zhang, W. & Zheng, C. (2006). Group: A grid-clustering routing protocol for wireless sensor networks. In: *Wireless Communications, Networking and Mobile Computing*, 2006. WiCOM 2006. International Conference on, IEEE, pp. 1–5.

Yuan, L., Zhu, Y. & Xu, T. (2008). A multi-layered energy-efficient and delay reduced chain-based data gathering protocol for wireless sensor network. In: *Mechronic and Embedded Systems and Applications*, 2008. MESA 2008. IEEE/ASME International Conference on, IEEE, pp. 13–18.

Zhu, J., & Papavassiliou, S. (2003). On the energy-efficient organization and the lifetime of multi-hop sensor networks. *Communications Letters, IEEE*, 7(11), 537-539.

